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XXXIV. *On the Transit of Venus in 1769.*

To the RIGHT HONOURABLE

The Earl of MORTON, President,

To the COUNCIL and FELLOWS

Of the ROYAL SOCIETY,

This DISCOURSE is, with all Humility, inscribed,

By their humble Servant,

Thomas Hornsby.

Read Feb. 13, 1766. **T**HE observations of the late Transit of Venus, though made with all possible care and accuracy, have not enabled us to determine with certainty the real quantity of the sun's parallax; since, by a comparison of the observations made in several parts of the globe, the sun's parallax is not less than $8''\frac{1}{2}$, nor does it seem to exceed $10''$. From the labours of those gentlemen, who have attempted

attempted to deduce this quantity from the theory of gravity, it should seem that the earth performs its annual revolution round the sun at a greater distance than is generally imagined: since Mr. Professor Stewart has determined the sun's parallax to be only $6''$, 9, and Mr. Mayer, the late celebrated Professor at Gottingen, who hath brought the lunar tables to a degree of perfection almost unexpected, is of opinion that it cannot exceed $8''$ *.

In this uncertainty, the astronomers of the present age are peculiarly fortunate in being able so soon to have recourse to another transit of Venus in 1769, when, on account of that planet's north latitude, a difference in the total duration may conveniently be observed, greater than could possibly be obtained, or was even expected by Dr. Halley, from the last transit.

The experience which we gained in the year 1761, the knowledge of the errors, from whatever cause they may arise, which must unavoidably be committed in observations of this kind, will enable us to put in practice every method of solving this problem, and to determine with what degree of accuracy, and within what limits, the true quantity of the sun's parallax may be obtained, and consequently the dimensions of the whole solar system.

But, before I proceed to give a computation of the effect of parallax at the several places where this transit ought to be observed, it will be necessary to premise the principles upon which the general calculus was

* Mr. Machin, Professor of Astronomy at Gresham College, deduced the same quantity many years ago. See a tract entitled *The Laws of the Moon's Motion according to Gravity*, p. 24.

formed. Having found, by computing the observations made on the transit in 1761, that, when the Abbé de la Caille's solar tables are used, the epoch of the mean motion of Venus for 1761, as given in Dr. Halley's tables, requires a correction of $+ 52'' \frac{1}{2}$; and that the place of the ascending node was, at the beginning of the same year, in $2^{\circ}. 14^{\circ}. 31'. 10''$: having collected also, by computing the observations of Mr. Horrox in 1639, with the assistance of Dr. Halley's tables of Venus, and the solar tables above-mentioned, that the motion of the planet's mean longitude is $6^{\circ}. 19^{\circ}. 12'. 22''$, and of the node $52^{\circ}. 18''$, in 100 Julian years: I have supposed the mean longitude of Venus, in the beginning of the year 1769, to be $0^{\circ}. 5^{\circ}. 23'. 48''$, and the place of the node to be in $2^{\circ}. 14^{\circ}. 35'. 21''$ —; and have assumed the rest of the planet's elements as given in Dr. Halley's tables. According to these numbers, and the Abbé de la Caille's solar tables, the ecliptic conjunction will happen on June 3d, 1769, at $9^{\text{h}}. 59'. 24''$ mean time at Greenwich, the planet's geocentric latitude being $10'. 13'', 5$ N. The log. of the earth's distance from the sun $= 5.0065166$; the log. of Venus's distance from the sun $= 4.8610947$; and of the planet's distance from the earth $= 4.4606784$; and the equation of the præcession of the equinoctial points $= + 17'', 7$. By computing the geocentric longitude and latitude of the planet three hours before and three hours after the ecliptic conjunction, I find the planet's hourly motion from the sun in the ecliptic $= 3'. 57'', 7$; the hourly motion in the relative orbit $= 4'. 0'', 3$; the hourly motion in latitude $= 0'. 35'', 45$; the angle of the planet's path with

with the ecliptic $= 8^{\circ}. 29'. 02''$; the angle of the ecliptic with the equator $= 7^{\circ}. 02'. 54''$; and therefore the angle made by the planet's visible path with the equator $= 15^{\circ}. 31'. 56''$. The geocentric latitude is, as has been observed, $= 10'. 13''. 5$; and hence it is easily determined that the least distance of the centers will be $10'. 06''. 8$, and the interval between the time of the ecliptic conjunction and the middle of the transit $= 22'. 21''$. of time. As the planet has not yet passed its node, the middle of the transit will therefore be at $10^h. 21'. 45''$ mean time at Greenwich. In every inferior conjunction the motion of Venus is retrograde, and therefore the effect of the aberration of light in long. $= 3''. 7$, when reduced to time $= 55''$, is to accelerate the several phases of the transit; the equated mean time of the middle, therefore, will be at $10^h. 20'. 50''$. But the place of the planet is also affected by the aberration of light in latitude; and as Venus's latitude is decreasing, the least distance of the centers will be increased by $1'', 35$. The equated least distance of the centers, therefore, will be $10'. 08'', 15$. Now, supposing the semi-diameter of the sun $= 15'. 45'', 6$, and of Venus $= 29''$, the semi-durations, or intervals between the middle and the external and internal contacts, will be found $= 3^h. 10'. 08'', 5$, and $2^h. 51'. 13'', 2$. The equation of time is about $2'. 14''$ at the middle of the transit, by which quantity the apparent time is before the mean, and decreases at the rate of about $2''$ in 6 hours. Therefore the apparent times of the several phases of this transit for the meridian of Greenwich are as follows.

	App. time.		
	h	'	''
First external contact, June 3,	7	12	56
Total ingrefs —————	7	31	52
Middle —————	10	23	04
Beginning of egresss ————	13	14	16
Last contact —————	13	33	11

Hitherto we have had no regard to parallax, and the above times are such as would be observed from the earth's center. To the British isles, and to the neighbouring parts of the continent, the effect of parallax is nearly at a maximum, and will considerably accelerate the times of external contact and ingrefs. If we suppose the sun's parallax on the day of the transit $= 8''.7$, the horizontal parallax of Venus from the sun will be $21''.87$; and the times of the external and internal contacts visible in England will be accelerated by the joint effects of parallax, both in the direction of the planet's path and perpendicular to it; the former by $7'.09''$; the latter by $7'.12''$. And therefore Venus will be seen to touch the sun's limb at $7^h. 5'. 47''$, more than an hour before the time of sun-set; when the apparent altitude of the planet above the horizon will be about 8 degrees: and the total ingrefs will happen at $7^h. 24'. 40''$, when the planet's altitude will exceed 5 degrees.— If the sun's parallax should be one second larger than we have supposed, or $9''.7$, the time of ingrefs will happen at $7^h. 23'. 51''$.

These times are not here given with any great degree of confidence: but as the errors in the planet's orbit will, in June 1769, be nearly the same with those

those which were observed 8 years before, it may be presumed that the foregoing computation will be found not to differ very widely from the truth.

Having rectified the globe to the declination of the sun at the middle of the transit $= 22^{\circ}. 26'. 40''$, and also at the times of the two internal contacts, I find that the whole transit will be visible to a considerable part of Swedish Lapland, the northernmost parts of Asia, and the northern and N. W. parts of North America; for the circle of illumination at the first internal contact passes along the western coast of Africa from Cape Verd through the Straits of Gibraltar to Clermont in France, leaving Paris about a degree and a half to the West; from thence it passes through Germany and along the Baltic Gulf, through Wi-bourg and Archangel, along the northern coast of Asia; and then traversing the N. E. parts of Siberia, it passes over Japan, enters the great Atlantic ocean, leaves the Marian isles and New Zealand on the West, and running round Cape Horn, and near Falkland isle, passes on to Cape Verd through the Ethiopic ocean, in a direction nearly parallel to the eastern coast of South America. All places situated under the first part of this line from Nova Zembla towards Cape Horn will see Venus enter upon the sun at the time of sun-setting, and at sun-rising under the other half of it. — The circle of illumination at the beginning of egress enters Europe to the North of Drontheim in Norway, and crossing the Bothnic and Finland gulfs, passes over Muscovy and the Caspian sea; and running through Persia traverses the Arabian gulf, going southward near the isles of Maldivia, and taking a large circuit towards the South

Pole, returns through Mexico, Louisiana, Canada, and the southern parts of Greenland, to Drontheim. So that almost all Africa is deprived of a view of this transit, and a very considerable part of Europe.

If we examine the observations of the transit in 1761, in places where there were more observers than one, and where the contacts were observed when the sun was near the horizon, and at higher altitudes, we may safely conclude that the observations will be made with sufficient accuracy when the sun is at such altitudes above the horizon, as not to be greatly affected by the vapours. At the Observatory at Upsal, when the sun's altitude at the ingress was $3\frac{1}{2}$ degrees, three observers differed $22''$, whereas at the egress, when the sun was $44^{\circ}\frac{1}{4}$ high, the difference amounted only to $6''$. It should seem, therefore, that observers ought not to be sent to places where the sun will be much less than 5° high at the time of either of the contacts.

It appears by computation, that the joint effect of the parallaxes both in longitude and latitude to lengthen the total duration, will be the greatest to those places which are about 24° or 25° to the East of Greenwich in the 66th or 67th degree of N. latitude, when the sun's altitude is about 5° at each contact, or if the sun's altitude at each contact be required $= 10^{\circ}$, the latitude of places under the same meridian must be 73° or 74° N. In the former case, this transit may be very advantageously observed at Tornea, Kittis, and the adjoining parts of Swedish Lapland; in the latter, at Wardhus, and in the neighbourhood of the North Cape: for an error of one or two degrees either in longitude or latitude will make but

but a very inconsiderable difference in the parallactic time; as will sufficiently appear from an inspection of the following Table, which contains the joint effect of the parallaxes of longitude and latitude in accelerating the times of the two internal contacts at Tornea°, Kittis, and Wardhus, for each of which places the parallactic angle, or the angle made by a vertical circle with the orbit of Venus, was carefully computed.

	First intern. contact	Second intern. contact	Total effect of par. = 8'',7	Total effect of par. = 9'',7	Difference for 1'' of parallax.
	/ /	/ //	/ //	/ //	/ //
Tornea°	6 53	4 47	+ 11 40	+ 12 58	1 18
Kittis	6 51	4 43	+ 11 34	+ 12 51	1 17
Wardhus	6 38	4 41	+ 11 19	+ 12 37	1 18

Having determined the greatest effect of parallax in lengthening the total duration at such places to which observers may conveniently be sent, let us examine how far we may be enabled to obtain observations in such parts of the earth's surface where the effect of parallax will be contrary; and consequently where the total duration will be as short as possible. By the assistance of calculation it may be found, that in the latitude of about 54° South, and in 155° of West longitude nearly, the total duration will be the shortest, when the sun's altitude is 5°; or in about 47° of South latitude under the same meridian, when the sun is 10° high. And accordingly, by computing the parallactic angle for the latitude of 55° South, and the meridian opposite to that of Tornea°, I find

that the total duration will be shortened by parallax no less than $12' 53''$, supposing the sun's parallax $= 8'',7$. and consequently that there might be observed a difference in the total duration between this place and Tornea° of $24' 33''$: a difference considerably greater than was expected by Dr. Halley in 1761; and, supposing with that astronomer, that the observations at each contact may be taken true to a single second, (which indeed experience will not warrant) sufficient to determine the sun's parallax within $\frac{1}{73.6}$ th part of the whole.

But as this and the other point fall in the great South sea, where it does not certainly appear that there is any land, let us enquire in what parts of the South sea we may reasonably expect to find land. From the accounts of some of the circumnavigators, it should seem that there are islands scattered here and there about the tropic of Capricorn, particularly the island or islands of St. Peter, in about 150° of W. longitude from Greenwich, and in about 21° of S. latitude. I have therefore computed the parallactic angle for a place $10^h 22' 50''$ to the West of Greenwich, and in 21° of S. lat. and find that the ingress will happen $6' 10''$ later, and the beginning of egress $6' 6''$ sooner, than if seen without parallax; that the total duration is therefore shortened $12' 16''$ by parallax; and consequently that there is a difference of $23' 56''$ in the total duration between Tornea° and this island, supposing the sun's parallax $= 8'',7$ on the day of the transit; or of $26' 39''$, if that parallax be supposed $= 9'',7$.

About the latter end of the 16th century, Don Pedro Fernandez de Quiros made two voyages for the

discovery of the southern continent and islands, under the patronage of the Viceroy of Peru. From several memorials which he presented to the court of Spain in the year 1609, with a view to procure a settlement of the countries he had actually discovered, it appears that he had found many islands, and particularly a large tract of land lying in or near the 15° of S. latitude, well peopled and well cultivated, the inhabitants generally of a peaceable disposition. The produce of this country is represented to be such as to render it a fit object to any commercial nation; consisting of gold, silver, pearl, spices of many sorts, and sugar-canes. He describes several safe and commodious harbours, particularly Puerto de la Vera Cruz in lat. $15^{\circ} 40'$ S. capable of holding 1000 ships, with a safe anchorage in every part; and where he himself actually staid thirty-six days with three ships. From the wholesomeness of the air, the fertility of the soil, and many other circumstances peculiar to this continent, he makes no scruple to prefer it to every country which the Spaniards had conquered whether in the E. or W. Indies*.—I must, however, observe, that, if this country be 195° to the W. of London, the whole of the transit, in all probability, will not be visible; as Venus will enter wholly upon the sun's disk at, or a few minutes before, the time of sun-rising.

The Spaniards gave the name of the Islands of Solomon to certain countries in the South seas, reported to be very rich in gold. They were first discovered by Alvarez de Mendoza in 1527, and are supposed by some to be the very lands which were afterwards found by Fernandez de Quiros. The Spaniards

* Harris's Voyages, 2d Edit. Vol. I. p. 63.

are said to have had very clear and satisfactory accounts of these islands; but to have destroyed them for political reasons, by express orders from Old Spain, when Sir Francis Drake sailed into the South seas *. Their situation is not known; and from some fruitless attempts to find them, it has been, and is still, perhaps, questioned whether there be any such islands. — Some time after the year 1720, while Capt. Betagh, Commander of the Marines on board of Capt. Shelvocke's ship, was in Peru, the discovery of these islands was again attempted, upon some fresh information, by command of the Viceroy †; but without success: for the latitude of these islands is not even nearly known. They are, however, supposed to lie between the 10th and 20th degree of S. latitude, in about 175° of W. longitude from London, according to the best English and French maps: or, according to some geographers, these islands are only 120° to the W. of London.

Soon after the government of the Dutch in the East Indies was settled at Batavia, it was thought proper by the Dutch East-India company that an exact survey of their countries already discovered should be made and preserved. For this purpose Capt. Abel Jansen Tasman sailed from Batavia in 1642. In this voyage several lands were discovered, particularly the two islands of Amsterdam and Rotterdam, lying in 21° and 20° of S. latitude and in 173° or 174° of W. Longitude. The islanders are represented to be of a civil and peaceable dis-

* Harris's Voyages, 2d Edit. Vol. I. p. 63.

† Id. ib. p. 245.

position, and to all appearance unacquainted with the use of arms; the lands well cultivated, and planted with all kinds of fruit-trees *.—Not far from these two islands are nineteen or twenty more, in 17° or 18° of S. latitude, and 4° or 5° to the W. of the former.

Mr. de Chabert, in the Memoirs of the Academy of Sciences for 1757 †, has given an account of four islands in the South sea, lying in about 10° of S. latitude, and 134° or 135° to the West of London, discovered in July 1595, by Alvaro Bendano de Neyra, commander of a Spanish squadron of four ships, in his second voyage for the discovery of the Solomon-isles.

“ The first and easternmost he named the Island of Magdalene. It is about six leagues in circuit, with high coasts and mountains in the middle; and is extremely well peopled. More than forty Indians came on board the ship.

“ To the N. W. at the distance of about ten leagues, lies the island of St. Peter, near three leagues in circuit, and presenting an agreeable prospect to the eye.

“ About five leagues to the S. W. of St. Peter is another and larger island, named Dominica, about fifteen leagues in circumference, well peopled, and affording beautiful prospects.

“ To the South of this island is St. Christine, near eight leagues in circumference.

* Harris's Voyages, 2d Edit. Vol. I. p. 327.

† Memoires de l'Academie des Sciences pour 1757, p. 50.

“ The whole squadron passed between this island and Dominica, and anchored in a very good haven, to the West of St. Christine, in the latitude of $9^{\circ} 30'$; near which they found a rivulet of very fine and fresh water. The coasts of all the islands seemed in general very safe and commodious for shipping.

“ In this harbour they found all kinds of refreshment; as fowls, hogs, sugar-canes, plantanes, cocoa nuts, and many sorts of other fruits.

“ They conversed with the natives of the country, and erected three crosses.”

Besides the countries already mentioned, it should seem from Mr. de Lisle's map of the southern hemisphere, that there are many islands situated between the parallels of 5° and 23° of South latitude in the great Pacific Ocean; the most remarkable of which, together with those already mentioned, are given in the following Table.

	W. Lon.	S. Lat.
Island of St. Peter, according to some maps	130	18
Islands of Mendoza	135	$9\frac{1}{2}$
Islands discovered by Quiros, 1605	138	21
Isles des Tiburons, or Dog Island	141	16
Ile Habitée	144	17
Islands of St. Barnard	150	11
Water Island	151	15
Fly Island	153	$15\frac{1}{2}$
Land discovered by Mendana	157	4
Ile de la Belle Nation	160	12
Island of Jesus	162	7
Rotterdam I.	173	$20\frac{1}{2}$
Amsterdam I.	174	21
Solomon Isles	175	10
Island of Taumaco	177	13
Prince William Islands	178	17
Terra Australis	190	15

It

It appears, I think, not only possible, but highly probable, that observers may be stationed in the South seas. I have, therefore, computed the parallaxic angle for different longitudes and latitudes, answering to such places whose positions seem to be most certainly known; the result of which calculations is given at one view in the following Table.

W. long.	S. lat.	Places Names.	First intern. contact	Second intern. contact	Tot. eff. of par. = 8", 7.	Difference in tot. dur. from Tornea°.
155 42	21 0	Island of St. Peter	6 10	6 06	12 16	23 56
135 0	9 30	Mendoza Isles	4 31	6 49	11 20	23 00
173 0	20 30	Amsterdam and Rotterd. I.	6 19	4 42	11 01	22 41
190 0	15 0	Terra Australis	5 43	3 16	8 59	20 39

By the last column it appears, that if an observer be stationed in any of the above places, perhaps in any part of the South seas where the whole transit is visible, and the total duration observed there be compared with that at Tornea°, we may obtain a difference in time from 20 to 24 minutes; which is indeed so considerable, that the sun's true distance must be ascertained more exactly than can possibly be expected from any other method.

But, if it should be found impracticable to station an observer in the South seas, the loss may in a great measure be repaired, if the transit be observed in such parts of North America where the whole is visible. At Mexico the total ingress will happen when the sun is very near the meridian; and, if the longitude of the place and the general computation may be depended upon, the beginning of egress will happen towards the time of sun-set, when the apparent altitude of the sun will not much exceed four degrees.

Observers therefore should be stationed farther to the West about Cape Corientes; at which place and at Mexico, though in about 20° of N. latitude, the effect of parallax will still be considerable, particularly at the egress, as appears from the following Table.

Places.	First internal contact.	Second internal contact.	Total effect of par. $= 8''.7$.	Difference in tot. dur. from Tornea°.
Mexico	1 07	5 03	6 10	17 50
Cape Corientes	0 26	5 00	5 26	17 06

By comparing the observations to be made at either of the above places, or in any of the neighbouring parts, with those of Tornea°, a difference of more than seventeen minutes in the total duration may commodiously be obtained; by which the quantity of the sun's parallax may be determined agreeably to the method proposed by Dr. Halley in the case of the last transit, and in which no error but that of the observation can take place, supposing the situation of the two places to be nearly known.

When Dr. Halley's computation was examined, and it was found that so great a difference in the total duration of the transit at any two places as had been expected could not conveniently be obtained; another method was proposed, and was accordingly carried into execution, viz. to station two observers in such a manner that one of the internal contacts might be observed with the greatest difference possible arising from a contrary effect of parallax at the two places. This method, though necessarily inadequate, because

because the longitude of the two stations must be rigorously known, may be practised at both contacts in 1769.

It appears by computation that the time of the first internal contact in the evening is accelerated as much as possible by parallax in $48^{\circ} 42'$ of N. latitude, and 6° to the East of Greenwich, at or near Nancy in France. But this computation is framed upon a supposition that the sun's center is in the very horizon : in which circumstances no observation can be taken. If the sun's altitude at the time of the contact should be required equal to 5 or 10 degrees, then it will appear that Greenwich and Dublin are stations very advantageous ; and we have already seen that the time of ingress at the former place will happen $7' 12''$ sooner than if seen from the earth's center, on account of parallax. Indeed the effect of parallax will be nearly the same to every part of Great Britain. The part of the earth's surface, where the effect of parallax upon the planet at the same contact will be as great as possible in a contrary direction, when the sun's altitude is about 5° , is in 46° of S. latitude nearly, and in 168° or 169° of W. longitude from London, in the great Pacific Ocean, where it does not at present appear that there is any land. If, however, an observer should be stationed in any of the islands in the South sea, for which a computation has already been made, even in the islands of Mendoza, the morning ingress will be found to be retarded by parallax $4' 31''$; and consequently a difference at this contact of $11' 43''$ may be obtained by comparing the observation of the first internal contact with the observations at Greenwich ; or $11' 24''$, if the same observation be compared with that at Tornea°.

In order to see the beginning of egress accelerated by the greatest effect of parallax possible, when the altitude of the sun is 5° , an observer must be stationed in about 123° of West longitude from London, and in about 19° of S. latitude; or, as it does not appear at present that there is land there, the observer may be stationed with considerable advantage either in the islands of Mendoza, or in the island of St. Peter. The same contact will be as much retarded on account of parallax to an observer placed under the tropic of Cancer, in about 67° of E. longitude from London. This point indeed falls into the Gulf of Sindi; but as a difference of many degrees, either in longitude or latitude, will occasion but a very inconsiderable difference in parallactic time, this contact may be very advantageously observed on any part of the coast from the mouth of the Indus to Cape Comorin, and from thence along the coast of Coromandel and Golconda as far as the mouth of the Ganges. It may naturally be expected that the end of the transit will, if the weather be favourable, be observed at many of our own settlements in these parts: I have therefore computed the effect of parallax at the egress for Madras and Calcutta, at which places the last transit was observed; and find that the time of the second internal contact will happen $6' 41''$ later on account of parallax at the former, and $6' 44''$ at the latter, than if seen from the earth's center. By comparing the observations made at either of the above places with the corresponding observation at Mexico, we may obtain a difference of $11' 44''$; a difference greater than could be obtained by any observations that could conveniently be made at the egress in the transit of 1761.

Upon

Upon the whole, the necessity of sending an observer into the South seas sufficiently appears, whether it be proposed to determine the sun's parallax by the difference in the total duration of the transit, or by the observations of the internal contacts either at the ingress or egress. For if there should happen to be no land in the meridian opposite to Tornea° and in about 21° of S. latitude ; yet if an observer can be stationed either in the islands of Mendoza, or in the islands of Amsterdam and Rotterdam, a difference in parallactic time will be obtained as in the following Table.

Places compared.	Difference in total duration.	Difference at ingress.	Difference at egress.
Tornea° and Mendoza Isles	23 00	11 24	11 36
Tornea° and Amsterdam or Rotterdam	22 41	13 12	9 29
Tornea° & the opp. merid. in 21 S. lat.	23 56	13 03	10 53

If the sky should prove favourable, the observations made at Tornea° and in any of the above places will enable us to determine the sun's parallax with great precision, and independent of the exact knowledge of the longitude of either place. But as the situation of Tornea° is perhaps very exactly known, if it should be convenient to the southern observer to continue long enough upon his station to determine the exact longitude of it, to which the situation of Jupiter at that time will greatly contribute, both methods might be practised at the same time, and they would mutually confirm and illustrate each other.

An opportunity of observing another transit of Venus will not again offer itself till the year 1874. It behoves us therefore to profit as much as possible by

by the favourable situation of Venus in 1769, when we may be assured the several Powers of Europe will again contend which of them shall be most instrumental in contributing to the solution of this grand problem. Posterity must reflect with infinite regret upon their negligence or remissness; because the loss cannot be repaired by the united efforts of industry, genius, or power. How far it may be an object of attention to a commercial nation to make a settlement in the great Pacific Ocean, or to send out some ships of force with the glorious and honourable view of discovering lands towards the South pole, is not my business to enquire. Such enterprizes, if speedily undertaken, might fortunately give an advantageous position to the astronomer, and add a lustre to this nation, already so eminently distinguished both in arts and arms.

Oxford, December 1, 1765.